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ON THE DYNAMICS OF REGULATED MARKETS:
CONSTRUCTION STANDARDS, ENERGY
STANDARDS, & DURABLE GOODS--
A CAUTIONARY TALE

BY

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ON THE DYNAMICS OF REGULATED MARKETS

Construction Standards, Energy Standards, and Durable Goods: A Cautionary Tale*

by

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and

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Revised: March, 1988

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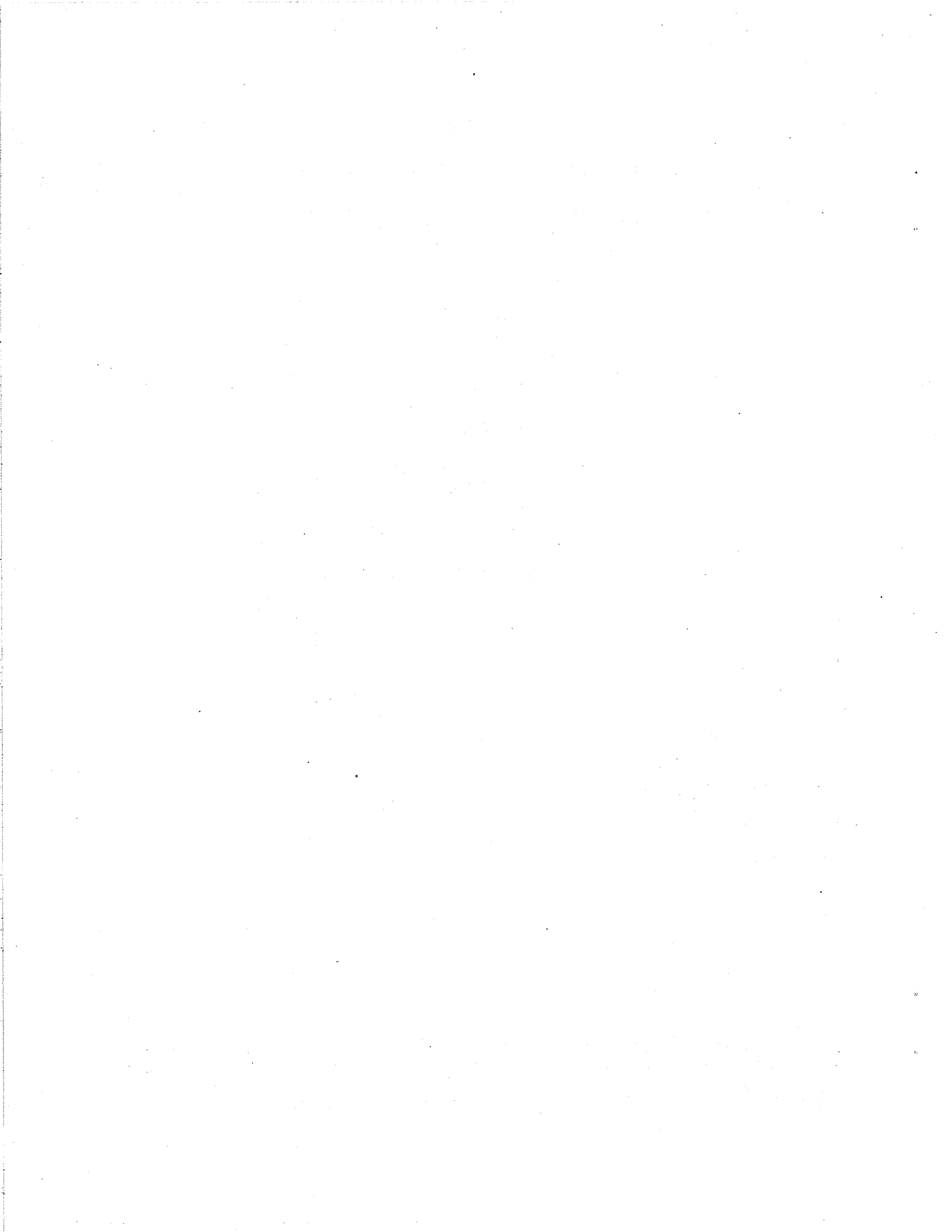
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ABSTRACT

This paper considers an increasingly important aspect of housing market regulation, namely the promulgation and enforcement of construction standards. The paper analyzes the problem of the consumer-investor who must choose a level of initial investment (or a government regulator who must mandate an investment) to produce a flow of housing services to maximize utility over some time horizon.

The optimal path of housing service flows and required operating inputs are characterized, using explicit functional forms and parameters drawn from related empirical research on the effects of standards in the housing market.

This control theoretic representation permits a dynamic analysis of how the system is affected by regulatory intervention which specifies or restricts the level of initial capital investment.

I. INTRODUCTION

Housing is different from many other commodities because of its long life and because it is quite costly to transform the housing stock once it has been put into place. The consequences of a decision about the design or configuration of a dwelling are felt by investors and consumers for forty years or more in the future.

The construction of housing is also affected by the important role of regulatory authorities in societies of very different market orientations. Many of the regulations imposed are designed to control market externalities, to protect consumers and producers from the consequences of their own ignorance, or otherwise to regulate public health and safety.

Certain other construction regulations are intended to enforce cost minimization or to promote x-efficiency in the market. Energy standards are a conspicuous example. These standards include various regulations specifying the amount of insulation, window glazing, and other aspects of the dwelling which affect its thermal properties. In contrast to regulations based upon externalities or information costs, these regulations can be evaluated by a straightforward benefit-cost test. Such regulations promote x-efficiency (or at least do not interfere with cost minimization) as long as the discounted savings arising from reduced energy utilization (evaluated at the social cost of energy) exceed the increased capital outlay in construction.

As noted, however, the appropriate time horizon for these calculations is quite long indeed, and the path of exogeneous prices is subject to great uncertainty. Despite this, the design of such regulations and the existing eco-

conomic analyses of the standards have been conducted in a static (or at least stationary) framework.

This paper considers these problems from a dynamic perspective. We analyze the problem of a consumer-investor who must choose a level of initial investment to produce a flow of housing services over some time horizon. Given the initial investment, the housing service flows obtainable from increased variable inputs are deduced. We characterize the optimal path associated with the solution to this problem.

We then particularize the problem by choosing explicit functional forms and parameters based upon related empirical research on the effects of standards in the housing market.

We consider how the motion of the system is affected by regulatory intervention which specifies or restricts the level of initial capital investment. The results presented here extend existing analyses of regulation in the housebuilding and residential construction industries.¹

Finally, we point out some serious limitations of this study. Within the context of the model, these have to do with the inadequate treatment of uncertainty about future prices, and the difference in individual and social treatment of time horizons. Beyond the specifics of this model, the limitations reflect a narrowly defined notion of the objectives of standards in the housing market.

¹ See Colwell and Kau [1982] or Quigley [1982] for analysis of the effects of the regulatory environment on housebuilders and final consumers.

II. THE MODEL

A. The Dynamic Optimization Problem

Consider the dynamic problem of the housing consumer who must choose at $t = 0$ the amount of real estate investment (e.g., insulation, glazing, etc.) to maximize utility over the relevant time horizon T . Let

$$(1) \quad U(H_t, X_t)$$

be the consumer's utility function for housing services (H_t) and other goods (X_t) at time t .

Assume housing services are produced according to the relationship

$$(2) \quad H_t = f(R, V_t) \quad ,$$

where the level of real estate, R , is chosen initially, and operating inputs V_t are adjusted at each point in time t . Let μ_t be the unit price of operating inputs. For convenience (and without loss of generality) assume that the unit prices of real estate and other goods are each equal to unity.

Denote the consumer's income at time t by Y_t and stock of savings by W_t . At an interest rate of $\bar{\delta}$, the rate of change of savings is

$$(3) \quad \dot{W}_t = \bar{\delta}W_t + [Y_t - X_t - \mu_t V_t] \quad .$$

The consumer must make real estate investments at $t = 0$ when wealth is

$$(4a) \quad W(0) = 0.$$

Discounted savings over the time horizon T must defray the initial investment

$$(4b) \quad W(T) = e^{-\delta T} R.$$

The consumer's problem is thus to maximize utility discounted at rate δ

$$(5) \quad \max \int_0^T U(H_t, X_t) e^{-\delta t} dt = \max \int_0^T U(f[W(T)e^{-\delta T}, V_t], X_t) e^{-\delta t} dt.$$

Utility maximization is subject to the constraints imposed by equations (2), (3), and (4). Equations (3) and (4) can be combined into a single budget constraint:

$$(6) \quad \tilde{Y} = \int_0^T Y_t e^{-\delta t} dt = R + \int_0^T \mu_t V_t e^{-\delta t} dt + \int_0^T X_t e^{-\delta t} dt,$$

and the income stream Y_t can be represented by an initial endowment, \tilde{Y} . To examine the properties of dynamic equilibrium for the consumer, consider the Hamiltonian

$$(7) \quad \theta(W, X, V, R, \lambda, T) = U(f[R, V_t], X_t) e^{-\delta t} + \lambda_t [\delta W_t + (Y_t - X_t - \mu_t V_t)]$$

At the optimum values λ_t^* , W_t^* , and R^* , the values of X_t^* and V_t^* must be chosen to maximize the Hamiltonian θ . At the optimum

$$(8) \quad \frac{\partial \theta}{\partial X} = \frac{\partial U}{\partial X} e^{-\delta t} - \lambda^*_t = 0$$

and

$$(9) \quad \frac{\partial \theta}{\partial V} = \frac{\partial U}{\partial H} \frac{\partial H}{\partial V} e^{-\delta t} - \lambda^*_t \mu_t = 0$$

The adjoint equation is

$$(10) \quad \frac{\partial \lambda^*}{\partial t} = \frac{-\partial \theta}{\partial W^*} = -\delta \lambda^*_t, \text{ or}$$

$$(11) \quad \lambda^*_t = e^{-\delta t} \lambda^*_0$$

Substitution into equations (8) and (9) yields

$$(12) \quad \frac{\partial U}{\partial X} = e^{(\delta-\delta)t} \lambda^*_0$$

and

$$(13) \quad \frac{\partial U / \partial X}{(\partial U / \partial H)(\partial H / \partial V)} = \frac{1}{\mu_t}$$

Finally, substituting for H_t in equation (5) and differentiating with respect to W_T yields

$$(14) \quad \lambda^*_T = \frac{\partial}{\partial W_T} \int_0^T U(f[e^{-\delta T} W_T, V_t], X_t) e^{-\delta t} dt$$

or, using (11) and (12)

$$(15) \quad \frac{\partial U}{\partial X} = \int_0^T \frac{\partial U(H_t^*, X_t^*)}{\partial H} \frac{\partial H(R^*, V_t^*)}{\partial R} e^{-\delta t} dt$$

Using (12) and (13), this expression can be simplified to

$$(16) \quad e^{(\bar{\delta}-\delta)t} \frac{\partial U}{\partial X} = \int_0^T \mu_t \frac{[\partial H(R^*, V_t^*)/\partial R]}{[\partial H(R^*, V_t^*)/\partial V]} e^{-\delta t} dt$$

To simplify calculations, we assume $\bar{\delta} = \delta$; then $\partial U/\partial X$ is constant, and we get

$$(17) \quad 1 = \int_0^T \mu_t \frac{[\partial H(R^*, V_t^*)/\partial R]}{[\partial H(R^*, V_t^*)/\partial V]} e^{-\delta t} dt$$

Equations (11), (12), (13) and (17) represent the equations of motion of the system. For a given income stream Y_t , interest and discount rate δ , and relative price stream μ_t , the dynamic pattern of consumption of operating inputs V_t^* , other goods X_t^* , and the initial investment in real estate R^* are determined, along with the adjoint variable λ_t^* .

B. The Case of Separable Utility

The solution to this dynamic system can be further simplified if the utility function is separable in its arguments. Suppose, δ and \tilde{Y} are given and that the utility function is

$$(1') \quad U = k(H_t) + g(X_t)$$

Under these circumstances, the dynamic system can be solved by trial and error. First, pick a trial value of the adjoint variable λ^*_0 . Solve for X^*_t from (12)

$$(12') \quad \frac{\partial U}{\partial X_t} = \frac{\partial g}{\partial X_t} = \lambda^*_0$$

Then solve for V^*_t as a function of the as yet unknown R^* , from (13)

$$(13') \quad \frac{\partial U}{\partial H} \frac{\partial H}{\partial V} = \frac{\partial k}{\partial H} \frac{\partial H}{\partial V} = \lambda^*_0 \mu_t$$

Then calculate R^* such that equation (17) is satisfied. Finally, check to see that the budget constraint is satisfied:

$$(6') \quad Y = R^* + \int_0^T \mu_t V^*_t e^{-\delta t} dt + \int_0^T X^*_t e^{-\delta t} dt$$

If the right hand side (RHS) of (6') exceeds the endowment \tilde{Y} , increase the trial value of λ^*_0 . If the RHS of (6') is less than the endowment, decrease λ^*_0 .

For the separable case, as long as equation (13') can be solved for V^*_t (as a function of R^*) in closed form, then equation (16) can be solved for R^* , by numerical methods if necessary. If utility is not separable in H and X , then the model may be much more difficult to solve, since (12') and (13') must be solved simultaneously for X^*_t and V^*_t , given a trial value for λ^*_0 .

III. SOME IMPLICATIONS

According to the model presented in Section II, the investor-consumer chooses the amount of real estate to purchase initially, assuming technical efficiency in production and knowledge of the time path of the price of operating inputs over the relevant planning horizon. The consumer makes this choice to maximize the present value of lifetime utility.

In this section, we use this model to analyze the imposition of standards which specify the amount of real estate R to be used in the production of housing. The analysis is highly stylized, to be sure, but we utilize empirical functions from a real housing market characterized by the recent imposition of energy standards. These standards are intended to increase the real estate component of housing and to economize on the operating costs, principally energy, associated with the flows of housing services enjoyed in final consumption.

We assume a separable utility function of the following form

$$(1'') U_t = \alpha H_t^\beta + X_t^\varepsilon ,$$

where α , β , and ε are parameters.

We also assume that housing services are produced from real estate and operating inputs according to a Cobb-Douglas technology

$$(2'') H_t = AR^{\delta_1} V_t^{\delta_2} = R^\nu V_t^{1-\nu}$$

By suitable choice of units of measurement this process can be represented by the single parameter ν .

The parameters of these relations, α , β , ν , ϵ are estimated from information about newly constructed single family dwellings and their occupants. These observations were obtained from U.S. government mortgage applications (under the Federal Housing Administration) in California during the period 1974-1978, before energy standards were introduced.

The production function is estimated from information on housing expenditures ($P_H H$), operating expenditures ($P_V V$), and real estate expenditures ($P_R R$) for this sample of dwellings. The parameters of the utility function are estimated from the first order conditions for utility maximization,² that is from a regression of the price of housing (i.e., the marginal cost of housing from the production function) on the quantities of housing and "other goods" (i.e., income minus housing expenditures) available for each household. A detailed description of the underlying data is available elsewhere.³

² From (1'') and the budget constraint

$$\frac{\partial U / \partial H}{\partial U / \partial X} = \frac{\partial P_H / \partial H}{\partial P_H / \partial X} = P_H' = \frac{\alpha \beta H^{\beta-1}}{\epsilon X^{\epsilon-1}}$$

³ See Quigley [1985] for a discussion of the underlying data and methodology. For present purposes it is important to note that the estimation of the production function assumes technical efficiency in the production of housing and the estimation of the first order conditions for utility maximization exploits individual variation in housing prices arising from variations in land prices and geographical variation in energy and capital costs.

Table 1 presents regression estimates of the two equations. In the regression of housing expenditures on real estate expenditures, constrained so that the intercept is zero, about three quarters of the variance is explained and the t-ratio is quite large by any standard. The estimate of v , $\exp(-.1352)$, is 0.874. The second equation explains about two thirds of the variance in the dependent variable, the log of the marginal price of housing, and the three coefficients are highly significant. The results imply values of α , β , and ϵ of 5.343, 0.974, and 0.910 respectively.

TABLE 1

Estimates of Utility and Production Function Parameters: 7378
California Households and Single Family Dwellings
(t-ratios in parentheses)

a. Regression Estimates:

1. Production

$$\log P_H H = 0 + [\log v] \log P_R R$$

$$\log P_H H = 0 - 0.1352 \log P_R R$$

(17.22)

$$R^2 = .766$$

2. Utility

$$\log P'_H = [\log \alpha\beta/\varepsilon] + [\beta-1] \log H + [1-\varepsilon] \log X$$

$$\log P'_H = 1.7442 - 0.0261 \log H + 0.0901 \log X$$

(11.14) (16.73) (3.39)

$$R^2 = .677$$

b. Implied Functions:

1. Production

$$H = R^v V^{1-v}$$

$$H = R^{.874} V^{.126}$$

2. Utility

$$U = \alpha H^\beta + \chi^\varepsilon$$

$$U = 5.343 H^{.974} + \chi^{.910}$$

With these parameters and the assumed functional forms, the dynamic system may be expressed more simply. Normalize the initial price of operating inputs, $\mu(0) = 1$, and assume that the expected price path for operating inputs is exponential

$$(18) \quad \mu_t = e^{\omega t}$$

Finally, choose the units in which the initial endowment is given so that $\lambda^*_0 = 1$. Under these circumstances the system simplifies, after some manipulation, to:

$$(19) \quad \frac{\partial U}{\partial X} = .91 X_t^{-.09} = \lambda^*_0$$

$$(20) \quad \frac{\partial U}{\partial H} \frac{\partial H}{\partial V} = .66 R^{.85} V_t^{-.88} = \lambda^*_0 e^{\omega t}$$

$$(21) \quad 1 = \int_0^T \frac{6.93}{R} e^{(\omega - \delta)t} dt = \frac{11.11 \lambda^*_0^{-1.14}}{R(.14 \omega + \delta)} [1 - e^{-(.14 \omega + \delta)T}]$$

The equilibrium consumption path is thus

$$(22) \quad X^*_t = 2.85$$

$$(23) \quad V^*_t = 6.68 \left\{ \frac{1 - e^{-(.14 \omega + \delta)T}}{(.14 \omega + \delta)} \right\}^{.97} e^{-1.14 \omega t}$$

$$(24) \quad R^* = 11.10 \left\{ \frac{1 - e^{-(.14 \omega + \delta)T}}{(.14 \omega + \delta)} \right\}$$

$$(25) \quad H^*_t = 7.74 \left\{ \frac{1 - e^{-(.14 \omega + \delta)T}}{(.14 \omega + \delta)} \right\} .87 e^{-0.14 \omega t}$$

Given the planning horizon, T , the interest rate, δ , the expected rate of price increase for operating inputs, ω , and the endowment \tilde{Y} , the initial investment in real estate R^* and the stream of operating inputs V^*_t are chosen. These choices define the stream of housing H^*_t and other goods X^*_t to maximize lifetime utility.

Consider the problem instead from the perspective of the public regulator who chooses an energy standard for newly constructed dwellings. Based upon expectations about the rate of price increase $\omega\#$, the regulator chooses a standards, $R\#$. If ω equals $\omega\#$, then the minimum standard is the same level as would be chosen in the absence of regulation. If $\omega\#$ is less than ω , then the minimum standard is not binding; investors and consumers choose a level of initial real estate investment that exceeds the mandated minimum. If, however, $\omega\#$ exceeds ω , then the consumer is forced to consume more "conservation" than is warranted by expected price increases over the planning horizon. Of course, if the regulator's forecast of price increases is more accurate than the private market's, then consumers are better off under the regulatory regime. If the consumer's forecast is more accurate than the regulator's, then the dynamic losses from regulation may be substantial.

Table 2 uses the theoretical model and the parameter estimates from the California housing market to investigate the dynamic efficiency of regulation under various assumptions about increases in the price of operating inputs. For a given planning horizon ($T = 40$ years) and interest rate, the optimal real estate investment, as well as the resulting discounted utility level, can be computed for given rates of energy price increase. Given an arbitrary level

of real estate investment, it is also possible to compute the discounted utility level for the consumer, for various rates of energy price increase. Thus, for example, for the level of real estate investment which would be optimal with a 10 percent rate of energy price increase, it is possible to compute the consumer's level of well being if energy prices increase by only 4 percent.

Each entry in the table represents the discounted utility lost by overly restrictive standards. The base is the discounted utility computed from the optimal real estate investment associated with a particular rate of energy price increase. For the same rate of energy price increase, the discounted utility is also computed using a mandated level of real estate investment which assume higher rates of price increase. The table reports the percentage difference in these levels of well being. The entries in the table thus indicate the dynamic inefficiency of regulatory standards which are too high relative to the optimally chosen level of real estate investment.

As the table indicates, the utility losses associated with overly stringent construction standards may be quite large indeed. Consumer welfare may be reduced by 15-25 percent if construction standards are based upon expectations of high rates of energy price increase relative to observed rates of increase.

TABLE 2

Consumer Losses from Overly Stringent Construction and Energy Standards

		Rate of Increase Assumed by Standard				
		5%	8%	10%	12%	15%
Interest Rate, δ 5%						
Actual Rate of Increase, w						
2%		11%	19%	28%	33%	36%
4		8	11	13	29	34
6		0	6	11	20	27
8		0	0	5	13	19
10		0	0	0	4	11
Interest Rate, δ 10%						
Actual Rate of Increase, w						
2%		12%	21%	29%	35%	38%
4		9	13	17	30	35
6		0	8	14	24	29
8		0	0	7	16	22
10		0	0	0	7	14

Entries represent discounted lifetime utility lost from overly stringent standards, in percent: $100(U_1 - U_2)/U_1$. U_1 is discounted utility at given values of δ and w in the absence of regulation. U_2 is discounted utility at the same values, given regulations which set R equal to the optimal level or each column entry. For example, at a 5% interest rate and a 2% rate of price increase, the total loss if efficient standards are set in anticipation of a 5% rate of price increase is 11 percent. Utility is computed from the solution to equations (6), (22), (23), (24), and (25).

IV. CONCLUSIONS

This paper analyzes a model of housing formulated to make explicit the choice between increased initial investments in insulation and other energy saving capital, on the one hand, and increased operating costs on the other hand. Crucial to the optimum level of investment is the expected increase in future energy prices.

The model is solved for numerical values using functional forms and parameter estimates for operating expenses and production relationships derived from a sample of newly constructed dwellings and their occupants in the California housing market during the period 1974-1978. Using these values, the model analyzes the dynamic efficiency associated with mandated energy standards, and computes the losses associated with regulation based upon overly pessimistic assumptions about the future course of energy prices.

According to the parameters and the solutions to the model, consumer well being could suffer by 15-30 percent from overly restrictive standards.

It is, of course, always dangerous to draw firm conclusions from overly simple models. The specific results and their application to a particular market depend upon a variety of simplifying assumptions and estimated parameters. Nevertheless, it is worth noting that the mandatory energy standards adopted by the California Energy Commission [1981] assume a real compound increase in energy prices of almost ten percent. The course of energy prices in the United States has been quite stable during the recent past; increases have averaged less than 0.5 percent a year during the past 7 years. If these trends continue, the losses from these standards may be quite large indeed.

However, one should not draw such a conclusion without appreciating the major limitations of this analysis. There are two sets of limitations: the first accepts the context of the model; the second goes beyond it. The crucial features about housing are extreme durability, the possibility of substituting between increased investment for insulation, etc. and increased operating expenses for energy, and the fact that optimum investment level depends on future energy prices.

The model analyzed in this paper clearly indicates how investment decisions based upon unrealized forecasts can lead *ex post* to substantial losses. It would, however, be incorrect to conclude on this basis alone that the particular California energy standards adopted in 1981 led to losses due to the pessimistic forecast of price increases. To substantiate such a conclusion one would have to show that the forecast was unduly pessimistic given the information available at the time it was made.

There is a rather different reason for higher mandatory construction standards arising if the time horizon T of the consumer-investor is too small. From equation (24) we observe that the smaller is T the smaller will be the optimal initial investment R^* . If it is costly to observe R^* once a building has been completed, then the initial value of R^* will be less than the social optimum.

The second set of limitations goes beyond the context of the model. Energy conservations measures (including building standards) may be based on considerations that go well beyond narrow standards of economic efficiency of the kind considered here. They may be based on concerns of ecology, national security, etc. Even granted, however, that these broader concerns lead to social decisions to conserve energy, the kinds of calculations suggested in this paper are

important in deciding how much conservation should be encouraged in different activities.

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